The impact of operational strategies on vessel handling times: a simulation approach

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Abstract: This paper reports a study of the ship loading and discharging process at a container terminal. Our objective was to analyse the impact of different operational strategies on vessel handling times in order to derive managerial insights that can be used by terminal operators to manage this key performance indicator. As a basis for our study, a simulation model was implemented, validated, and verified to gain insight into the containers loading and discharging process. Four scenarios were constructed to resemble possible instances under which a vessel would operate at a Mexican container terminal, with the different operational strategies that were designed and evaluated for each scenario. An experimental framework was proposed, based on comparisons of scenarios and search experimentation, and employing a fractional factorial design to evaluate the impact of several factors on the vessel handling times. Our results emphasise that with an adequate design of the operation parameters, combined with the implementation of efficient stacking policies; it is possible to keep VHT under control. Conclusions and recommendations for further research are also discussed.

Keywords: container terminals; simulation analysis; vessel handling times; VHT; operational strategies; port logistics.

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1 Introduction

Container terminals are strategic nodes in the global transport chain that compete in a very dynamic environment. Container terminals constantly face the pressure from business sectors and stakeholders to increase terminal throughput and capacity, and in particular, to decrease vessel handling times (VHT). The VHT is the total time it takes to discharge all containers from the vessel and upload new containers onto the vessel. The speedy transfer of containers to and from vessels is a major challenge in coping with the growing volume of foreign traffic, and the introduction of larger vessels, which increase logistics complexity at ports.

The containership loading and discharging process is made up of very complex tasks, which require the coordination of seaside and container yard (CY) planning decisions. Prior to the arrival of the vessel at the container terminal, it is necessary to receive and stack export containers in the yard. Here, several CY decisions that will affect the VHT are made. These include:

1. the assignment and scheduling of yard handling equipment (Gharehgozli et al., 2014)
2. the assignment and scheduling of personnel to the different tasks (Legato and Monaco, 2004; Hartmann, 2004; Fancello et al., 2011; Di Francesco et al., 2015)
3. the stacking of containers in the yard (Zhang et al., 2003; Euchi et al., 2016)
4. the pre-marshalling issues (Expósito-Izquierdo et al., 2012; Bruns et al., 2016)
5. the relocation of containers, i.e., the block relocation problem (Caserta et al., 2012; Zehendner et al., 2015, 2016; Expósito-Izquierdo et al., 2015).

All these decisions together affect not only the number of rehandles required when a container is retrieved to be uploaded onto a vessel, but also the organisation of the yard.

At the seaside, the terminal operator has an estimated time of arrival for the incoming vessels. Based on that, and considering also operational constraints and various objectives, the following are determined:

1 the berth schedules (Bierwirth and Meisel, 2015; Cordeau et al., 2005; Lalla-Ruiz et al., 2012)

2 the assignment and scheduling of quay cranes and yard cranes (Meisel and Bierwirth, 2015; Lalla-Ruiz et al., 2014; Iris et al., 2017; Sha et al., 2017)

3 the number of internal trucks or vehicles that will move the containers between the yard and the vessel area (Lee et al., 2009; Niu et al., 2017).

Once the vessel arrives at the container terminal, the terminal manager, with the captain of the vessel, defines the stowage plan that defines the loading and discharging sequence of the containers. It considers the structural and operational restrictions of the vessel, such as its route, making it suitable for the current and future ports of call (Ambrosino and Sciomachen, 2003; Kim et al., 2004; Ding and Chou, 2015).

With all these decisions made, the loading and discharging operations begin. Typically, containers are first discharged from the vessel onto vehicles by quay cranes the vehicles which then transport the containers to various storage locations in the yard area, where yard cranes take the containers and place them on the block of containers. After most, or all, of the containers have been discharged from the vessel, outbound containers are loaded onto the vessel. These containers are carried by vehicles from the yard to the vessel area, and are loaded onto the vessels by the quay cranes.

Clearly, the efficiency of the loading and discharging process can be greatly improved with well-designed operational strategies that take the interrelationships between seaside and yard side planning decisions into consideration. In this paper, an operational strategy is defined as a set of decisions made by the terminal operator that will affect the cargo transfer between the vessel and the yard, and vice versa. We concentrate on analysing the impact of various operational strategies on VHT. These operational strategies include the decisions made and related to:

1 the seaside equipment assignment and scheduling

2 the yard side equipment assignment and scheduling

3 the stacking of containers

4 the dispatching of containers to external trucks.

Considering the previous discussion, the goal of this paper is to provide and derive managerial insights that can be used by terminal operators when managing VHT. In this regard, we define various operational strategies that are evaluated considering as case study the Port of Altamira in Mexico. In the following, we list the main contributions of this study:

- An analysis of the container loading and discharging process is provided. This includes the identification of the main factors involved in the loading and discharging process on the VHT.

- In order to assess the performance of VHT, we propose well-defined scenarios and operational strategies that consider the main factors that were previously determined to be significant.
- An experimental framework that cover the use of a simulation model and a comparison of scenarios. Based on the results obtained, we extract recommendations within a framework of specific actions that should be carried out by terminal operators to improve the efficiency of their loading and discharging operations.

The remainder of this paper is organised as follows: In Section 2, there is a review of the literature related to the loading and discharging operations, and the strategies that have been employed to reduce VHT. In Section 3, the loading and discharging process is described and the problem defined, while in Section 4 a simulation model used to analyse the impact of operational strategies on VHT is described. The experimental framework and the numerical results are provided in Section 5. Section 6 discuss the managerial insights derived from the study. Finally, in Section 7 conclusions and further research directions are identified.

2 Literature review

Vessels are the main assets of the shipping lines. These assets generate revenue when cargo is moved from one port to another, and hence the time spent by vessels alongside a terminal for loading and discharging of containers has to be as short as possible (Ku et al., 2010).

Most of the studies reported in the literature related to the loading and discharging operations aim to analyse the impact of automation on VHT (Kim and Kim, 1999; Liu et al., 2002; Kim and Bae, 2004; Vis and Harika, 2004; Lokuge and Alahakoon, 2007; Kim et al., 2013), determine the optimal assignment of terminal resources (i.e., quay cranes, yard cranes, and internal trucks) to reduce VHT (Azimi and Ghanbari, 2011), evaluate the impact of resource cycle strategies (Zeng et al., 2015; Lee et al., 2015) on it, or assess the efficiency of cargo-handling operations at a container terminal and study the factors influencing it (Luna et al., 2018). Bish et al. (2005) study the problem of dispatching vehicles to the container efficiently so as to minimise VHT. Zhang et al. (2002) argue that efficient loading and discharging of vessels is related to optimal deployment of yard cranes, proposing a Lagrangean relaxation algorithm to solve the dynamic yard crane deployment problem. Dulebenets et al. (2015) use a simulation model to evaluate the storage of container off-shore strategy during the vessel loading and discharging process with the aim of minimising VHT. He et al. (2015) propose an optimisation-simulation approach to solve the integrated problem of quay crane scheduling, internal truck scheduling, and yard crane scheduling, aiming to minimise the total departure delay of vessels. Ji et al. (2015) present an optimisation model to minimise the number of rehandles, integrating the loading sequence of a vessel with the parallel operation of multi-quay cranes. Karam and Eltawil (2016) propose a functional integration approach for berth allocation and quay crane assignment problems aimed at reducing VHT.

Recent surveys on operations research applications to support planning decisions of terminal operations show an increasing interest in the design and analysis of operational strategies with analytical methods (Stahlbock and Voß, 2008; Monfort et al., 2012; Carlo et al., 2014, 2015; Bierwirth and Meisel, 2015). On the yard side, few studies report the design of operational strategies, which can be categorised according to Saanen and Dekker (2007) as follows:

1 Dedicated versus non-dedicated, depending on whether or not containers to be loaded on different vessels occupy the same block
2 Consolidated versus dispersed, depending on whether or not the containers to be loaded on the same vessel are grouped into clusters
3 housekeeping versus immediate final grounding, depending on whether or not the containers to be loaded are shifted to favour the loading process
4 discharge-optimised grounding versus loading-optimised grounding.

A discharge-optimised grounding strategy stores the containers to maximise the efficiency of the storage activities, while a loading optimised grounding strategy stores the containers to maximise the efficiency of retrieval activities at a later time. Lehnfeld and Knust (2014) present a review of the loading, discharging, and pre-marshalling of stacks problems in storage areas, which provides an overview of storage problems when the storage area is organised in stacks.

Our study encompasses what Iris and Pacino (2015) call the ship loading problem. The ship loading problem is comprised of the integration of four terminal planning problems:

1 operational stowage planning (Sciomachen and Tanfani, 2007; Monaco et al., 2014)
2 load sequencing (Imai et al., 2002; Li, 2015)
3 equipment assignment
4 equipment scheduling (Bish et al., 2005; Chen et al., 2007; Lau and Zhao, 2008).

According to Iris and Pacino (2015) the ship loading problem is an integrative approach that considers the management of the loading operations, the planning of which quay and yard equipment to use and their scheduling, with a vision beyond the terminal's operations, incorporating the shipping line's decision making. We employ a simulation model to analyse the impact of different operational strategies on VHT. Simulation models have been proposed in the literature to support the design and evaluation of various terminal planning problems at container terminals (Duinkerken et al., 2001; Lee et al., 2007; Yan et al., 2008; Legato et al., 2008, 2009; Zeng and Yang, 2009; Legato and Mazza, 2013; Pascual et al., 2016; Keceli, 2016; Cimpeanu et al., 2017), making them suitable tools to deal with our problem at hand. The reader interested in simulation and optimisation models for planning and scheduling resources at container terminals is referred to Chen et al. (2003) and Dragović et al. (2016).

3 Background

Container terminal operations require the use of specialised equipment and planning capabilities in order to serve the incoming vessels mooring at the yard by transferring containers efficiently. Prior to the arrival of the vessel at the container terminal, it is necessary to receive and stack export containers in the yard. Container terminals have predefined locations (container blocks) for stacking containers, which define a yard's configuration. This yard configuration depends strongly on the layout of the yard, the availability of yard and seaside equipment, and the contractual agreements with the shipping lines. For instance, some container terminals may offer a preferred space for the containers of a certain shipping line, requiring reshuffling operations for those containers, which is known as housekeeping. In other cases, container terminal managers may require pre-marshalling the containers as a policy to ensure that they fit the loading sequence, defining a pre-marshalling area within the yard to receive them, and reshuffling them according to the loading sequence. Pre-marshalling occurs if containers require sorting inside the storage area so that all of them can be retrieved without any, or with minimal, further reshuffling afterwards. During the receiving process, pre-marshalling may be performed with the goal that at the end of the stacking process, all containers can be retrieved without any additional reshuffling (Lehnfeld and Knust, 2014).

When the vessel arrives at the container terminal, the terminal operator makes some decisions related to the use of terminal resources (i.e., quay cranes, yard cranes, and internal trucks). When all these decisions have been made, the loading and discharging process begins. Figure 1 shows a flow chart of a typical loading and discharging process. During the loading and discharging operations, the terminal operator must make some additional decisions to expedite the flow of the containers to and from the vessel. These include the definition of:

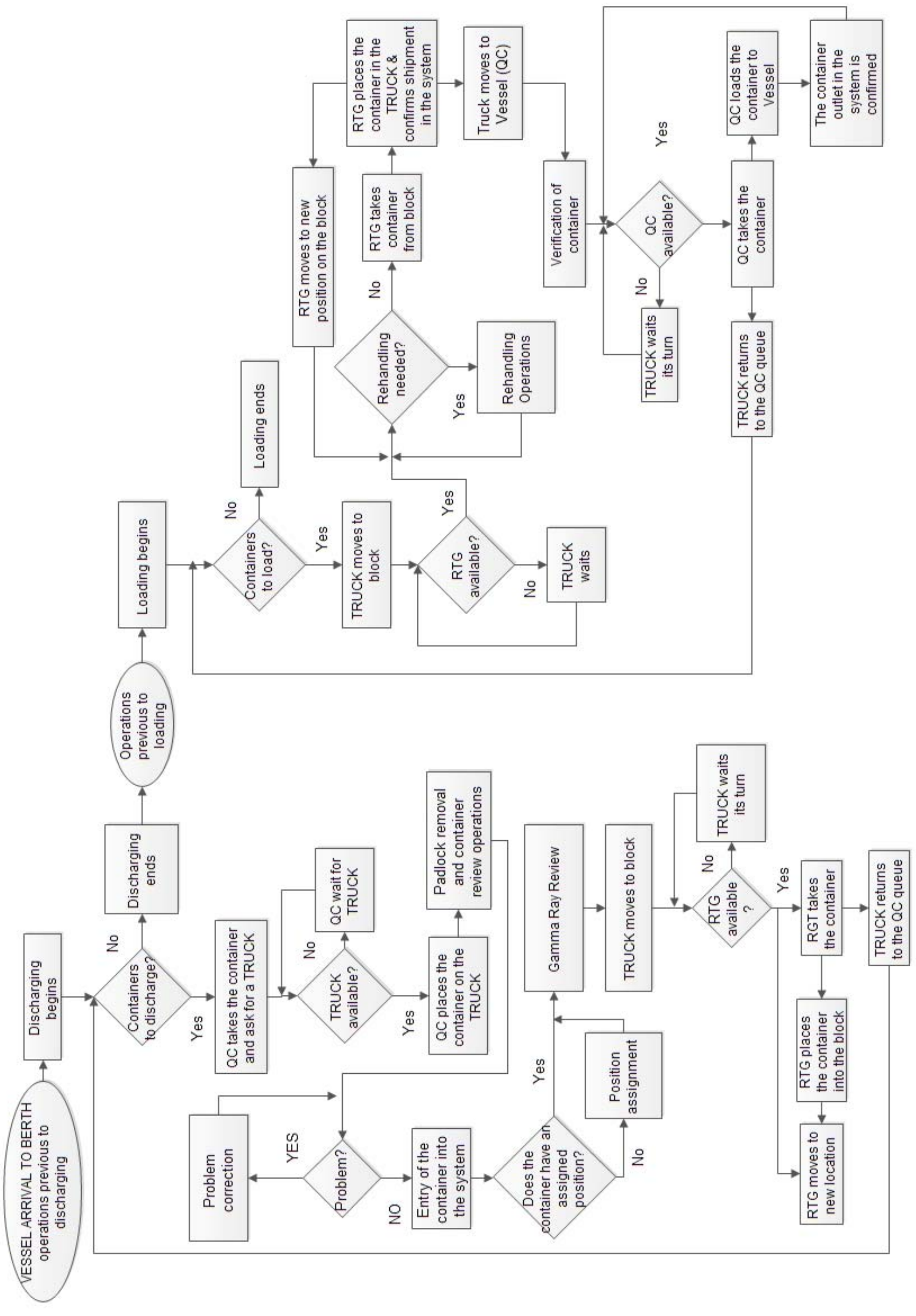
1. the stacking location of import containers when unloaded from the vessel
2. the schedule for dispatching import containers to the external trucks.

These operations (stacking and dispatching) may occur simultaneously in the yard, causing internal congestion if they are not planned function efficiently.

In practice, all these decisions are made by planners and yard operation supervisors according to their empirical experience; however, they lack the analytical, theoretical support of how these decisions will affect the VHT. Thus, in this paper we aim to analyse the impact of interrelated decisions on VHT, in order to provide recommendations based on various scenarios that are designed and evaluated. To do so, an experimental framework, based on comparison of scenarios and search experimentation (Hoad et al., 2015) is proposed.

For the sake of reality, we use the data provided by a Mexican container terminal located on the port of Altamira, which is the second largest Mexican port on the Gulf of Mexico, moving, on average, more than 600,000 containers per year, and connecting to over 20 major ports worldwide. Altamira Port Terminal (ATP, its acronym in Spanish) is one of the two container terminals operating in the port of Altamira, and was the focus of this study, providing the raw data. Approximately 60% of the cargo is transported within a radius of about 120 kilometres from the port, and 40% within a radius of 250 kilometres. It should be noted that although ATP is unique, the process and the general characteristics described here are similar to those of other container terminals. Therefore, the ship loading and discharging process is quite general, and the methodology, with slight modifications, is suitable for other container terminals as well.

Figure 1 The loading and discharging process



4 Simulation model

A detailed simulation model, adapted according to the specific characteristics of the ATP terminal, was implemented using System Modeling Corporation's Arena 5 software. We began with a model of the current system, which was later modified to model and analyse various operational strategies and scenarios. The simulation model was used to capture the dynamics and stochastic of the container flow within the container terminal. Table 1 summarises its main assumptions.

Table 1 Main assumptions, inputs and setting of our simulation model

Main assumptions, inputs, and settings:

- The yard configuration is given, i.e., the size of the yard, the type of yard cranes, and the number of yard cranes.
- Historical data of the ship arrivals and the associated VHTs were collected through a data survey in the ATP terminal, for the first quarter of 2015.
- Our simulation is a terminating, non-steady state model.
- The model runs until all containers have been loaded and discharged, and then stops.
- Each run was replicated 50 times.
- When a vessel arrives at the terminal, the following information is known:
  1. the number of containers to move
  2. the number of containers to discharge
  3. the number of containers to load
  4. the number of containers to transfer
  5. the time of arrival of the vessel.
- The terminal has already defined the berth allocation for the vessel.
- The terminal knows how the containers are distributed within the yard (as a consequence of previous decisions and strategies), and hence it knows the number of blocks to load and discharge.
- It is assumed that with the workload information, the terminal manager makes decisions on:
  1. the operational stowage planning
  2. the loading and discharging sequence
  3. the quay crane assignment and scheduling
  4. the number of trucks required per quay crane
  5. the yard crane assignment and scheduling for the exclusive dedication to the vessel.
- As a consequence of the previous yard side stacking decision, it is possible to determine:
  1. the percentage of containers to be reshuffled
  2. the percentage of double moves, i.e., moving two containers at a time.
- At the real-time level, the terminal manager may decide to:
  1. avoid receiving containers from external trucks in the block at which a vessel is being loaded
  2. assign the unloaded containers from the vessel to the blocks where there are fewer deliveries to external trucks.
- The double cycle strategy is not considered; the loading and discharging process that is modelled implies that each quay crane begins the discharging of the assigned containers, and then continues until the last container is discharged, when the loading of containers begins.

4.1 Data collection

Operational historical records for a six month-period, from May to October 2015, were provided by ATP. The historical records detail the total number of containers moved and the associated times for each container in the loading and discharging process. The complete data base, comprising more than 160,000 records corresponding to the service of more than 150 vessels, was analysed to obtain the number of quay cranes, trucks, and yard cranes used in the operations, as well as the bay of origin in the block and the sink bay in the vessel, for the loading operations, and vice versa for the discharging operations. The productivity of the handling equipment and associated VHT times were computed.

A basic statistical analysis shows an average VHT of 10.89 hours, with a standard deviation of 4.10 hours. The linear regression model developed from the historical records generated the following equation (1):

$$\text{VHT} = 2.64 + 0.0122\,x \tag{1}$$

where x is the number of containers to move. The results indicate that the regression model is significant (p-value = 0.000), and explains the 71.6% of the observed variability (adjusted $R^2 = 0.716$). For the rest of the parameters, goodness-of-fit tests were performed to determine the probability distribution of the data. For example, the unit operation time for yard cranes to load or unload a container follows triangular distribution of [4.02, 4.96, 5.58] minutes, and the processing time for the quay cranes follows log-logistic distribution of [1.0, 3.17, 0.872] minutes.

4.2 Validation and verification

Before evaluating the impact of the operational strategies for each scenario under study, considerable effort was expended to verify and validate the model for the current system. This work included careful trace studies, detailed animation to verify proper system behaviour, and a review of the model behaviour (via animation) and numerical output results with system experts at the container terminal under study. Verification is the process that ensures that the simulation model mimics the real system. Since this model is large, with many types of entities (quay cranes, yard cranes, trucks, and containers) in the system, the verification process requires that every container has to be traced and checked to ensure that it follows its required sequence.

In order to verify that the model represented the real system adequately, the first step was to check the code, and verify the model logic and the experimental conditions; followed by a careful trace study in which various entities were followed from the point of entry to the point of disposal from the system. Finally, a detailed animation was used to further verify that the model replicated the real system sufficiently. Validation of the model calls for comparing outputs of the simulation to those of the actual system. Measures that are included (for which actual data were available) are described in the next section. Given a predefined number of containers to move (discharge and load), the simulation model runs until the last container is loaded into the vessel, and then stops, so that the model can be validated.

4.3 Simulation analysis and variance reduction

Our simulation is a terminating, not steady state model. The model runs while there is a container to move, then stops. Following general recommendations for terminating systems, each run was replicated 50 times. The number 50 was chosen as the number of replications because the trade-off between statistical confidence and computing time appeared optimal in the context of this application. This number is bigger than the result obtained by the equation proposed by Garcia et al. (2006) to compute the approximate number of replications in a simulation study. Furthermore, more than 2,400 replications were computed in all the required experiments. No variance reducing techniques were used because enough replications of the simulation model were carried out, and the consistency of their associated response variables proved to be satisfactory. Groups of replications within scenarios and conditions were checked for possible outlier runs. No such runs were found, and there was good homogeneity among the conditions within the scenarios.

4.4 Performance indicators

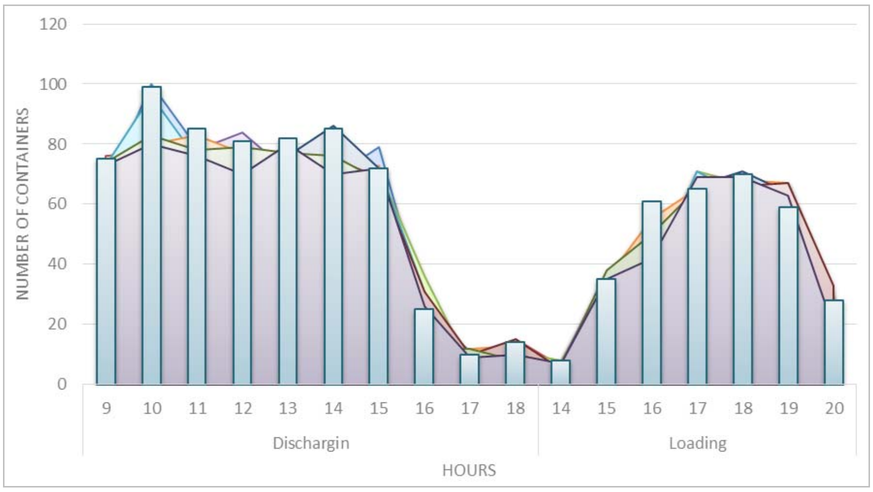
In order to quantify the performance of the system, the VHT was collected after each simulation run, since it accounts for the total time it takes to discharge and upload all the containers in a particular instance.

4.5 Simulation of current situation

With the aim of validating the simulation model, the existing situation of a particular vessel was simulated. From this vessel, in addition to the operational conditions (the number of containers to move, the assignment and scheduling of workload by quay cranes, the number of trucks assigned per quay crane, and the number of yard cranes used), the status of externalities (good weather conditions and no equipment failures) were also known. That situation was simulated, and the simulation results compared with the real data. Figure 2 shows the comparison between the existing situation and the simulation results. The size of each bar indicates the number of containers discharged and loaded per hour, for a scenario in which 814 containers were moved (547 for discharging and 267 for loading), using 2 quay cranes and 5 trucks per quay crane, with 3 blocks for loading and 2 blocks for discharging, starting operations at 9 am. Grey areas show the behaviour of 50 replicates of the simulation model.

Several meetings with the managers of ATP were required, first, to identify a base case for which a particular vessel that presented clear and usual operational conditions could be selected; and then to validate the simulation performance and results. The numerical outputs from the simulation are all within the range of the actual data. The existing situation showed that the average cycle time for discharge varied from 4.89 to 8.33 minutes, while the average cycle time for loading varied from 5.96 to 9.73 minutes. The simulation results indicate that the average cycle time was 6.45 min. and 7.56 min. for discharging and loading, respectively. In the actual situation, the VHT was 10.4 hours, while the simulation showed an average VHT of 10.8 hours, with a 95% confidence interval, between 10.39 and 11.05 hours. Therefore, the results show that the numerical simulation model outputs are within the ranges of the actual situation.

Figure 2 Comparison of the current situation and simulation results (see online version for colours)



5 Experimental results and analysis

5.1 Experimental factorial design

This section describes the experimental framework used to analyse the impact of the main factors involved in the loading and discharging process, for which there is an empirical conjecture affecting the VHT. What is at issue here is to perform a sensitivity analysis on the VHT when varying the factors under consideration. It aims to identify the critical factors that are used to define the scenarios and the parameters of the operational strategies with which to measure the potential impacts. Seven factors for which there is an empirical conjecture affecting the VHT were considered:

a total number of containers to move: (750 containers, 1,200 containers)

b loading/discharging relation: (45/55 balanced, 35/65 unbalanced)

c number of quay cranes assigned: (2 quay cranes, 3 quay cranes)

d number of trucks assigned per quay crane: (6 trucks, 8 trucks)

e number of blocks at the yard from which containers are retrieved to be loaded: (2 blocks, 4 blocks)

f number of yard cranes assigned: (3 RTG, 6 RTG)

g percentage of rehandles incurred when a container is retrieved in the loading process: (0.5%, 1.0%).

The total number of containers to move defines the workload for the vessel's service; few containers need to be transferred in some vessels, while others require a larger number of movements. The loading and discharging relation at a container terminal defines whether the terminal is oriented to export activities, or to import activities. When serving a vessel, the loading and discharging relation defines the percentage of containers to be loaded onto and discharged from a vessel. This factor is considered because it is assumed that the two operations require different times. The impact on VHT of the number of trucks per quay cranes has been widely studied and reported in the literature, (Grunow et al., 2006), demonstrating that this is an important factor. The number of blocks in which containers are stacked depends not only on the number of containers to be transferred, but also on the stacking policy at the yard, and the availability of space.

Table 2 Design table (randomised), fraction factorial design 2^{7-2}

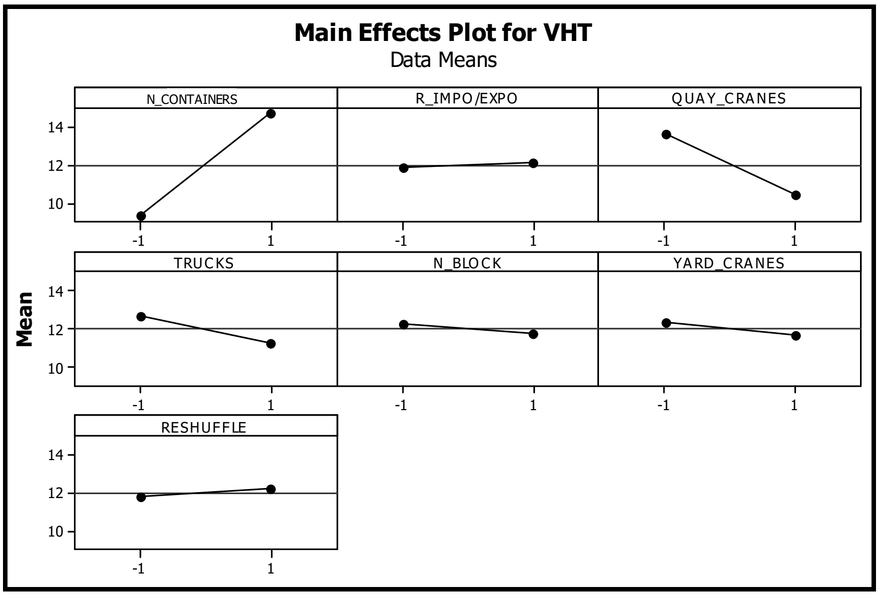
Run	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*VHT*
1	+	+	–	+	–	–	–	15.95
2	–	+	–	–	–	–	–	11.60
3	+	–	+	–	–	+	–	12.47
4	+	+	–	–	–	+	+	17.66
5	+	–	–	–	+	–	+	18.51
6	+	–	–	+	+	+	–	14.88
7	+	–	+	+	–	–	+	14.40
8	+	+	–	–	+	+	–	17.61
9	–	–	+	–	–	–	+	8.91
10	–	+	–	–	+	–	+	11.49
11	–	+	–	+	–	+	+	9.73
12	–	+	–	+	+	+	–	10.27
13	–	–	–	–	+	+	–	10.90
14	+	+	–	+	+	–	+	15.35
15	+	–	+	+	+	–	–	11.21
16	+	+	+	+	+	+	+	11.28
17	–	–	–	+	–	–	–	9.83
18	–	+	+	+	+	–	–	7.41
19	–	+	+	+	–	–	+	8.97
20	+	+	+	–	–	–	+	14.90
21	–	+	+	–	–	+	–	8.18
22	–	–	–	–	–	+	+	10.86
23	+	–	–	+	–	+	+	14.81
24	–	–	+	+	–	+	–	7.27
25	–	–	+	+	+	+	+	7.91
26	+	–	+	–	+	+	+	12.31
27	–	–	–	+	+	–	+	9.49
28	+	+	+	–	+	–	–	12.92
29	–	–	+	–	+	–	–	7.99
30	+	+	+	+	–	+	–	11.85
31	+	–	–	–	–	–	–	18.64
32	–	+	+	–	+	+	+	8.98

Note: Design generators: E = ABCD, where – and + implies lower and upper level for each factor.

Based on an actual case, we consider the situations where containers to be loaded are stacked in either 2 or 4 blocks at the yard. The number of yard cranes defines the number of resources used at the yard for servicing the vessel. Whether or not the container terminal implements a housekeeping strategy depends upon the percentage of rehandles needed when containers are retrieved in the loading process. When a housekeeping strategy is implemented, fewer rehandles are needed. Neither the operational factors that can be controlled by the design of standard working procedures, such as the time it takes an operator to check containers, or the ability of equipment operators, nor the analysis of externalities that can be avoided by accurate programming methods, such as the fact that a given container doesn't have an assigned position in the yard, among others, were considered. It is expected that all these cases constitute the greatest contribution to the unexplained variability in the ANOVA.

A randomised fractional factorial design study 2^{7-2}, with fraction 1/4 and resolution IV, was proposed in order to appraise the significance of controllable and uncontrollable factors affecting VHT. Thus 32 experimental situations (see Table 2) were simulated, each with 50 different replications, in which the response variable was recorded. Thus 1,600 simulation runs were carried out in this experiment. Under this experimental design, the alias structure reveals that there is no confusion with any main effect and/or two-level interaction.

Figure 3 Main effects plot



The main effects plot in Figure 3 shows the impact of each factor on VHT. As expected, the number of containers to move is the main determinant of the VHT variability. Results indicate that the average VHT increases as the number of containers to move increases, whereas the average VHT decreases as the number of quay cranes and trucks increases. The relation between the number of containers to discharge and load, and the percentage of rehandles is not significant. The interaction plot (see Figure 4) shows that the discharging/loading relation interacts with most of the other factors, while the total number of containers to move doesn't show interactions. However, factors B and E do not have an effect on the response variable.

Figure 4 Interaction plot (see online version for colours)

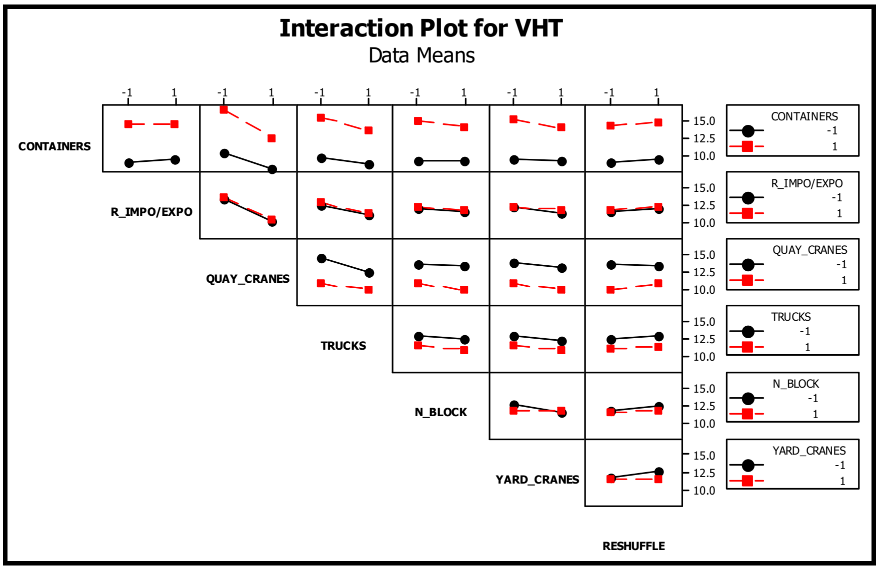
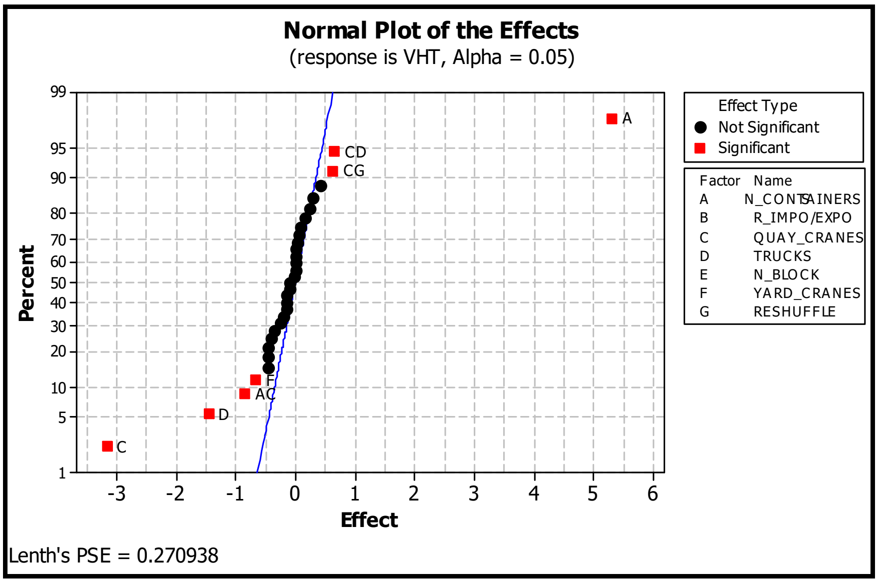


Figure 5 Normal plot of the effects (see online version for colours)



The normal plot of the effects (see Figure 5) shows that the number of quay cranes (C), the number of trucks per quay crane (D), and the number of yard cranes (F) are significant for average VHT, with a negative effect. The interaction AC (number of containers to move and number of quay cranes) is significant, which means that the number of quay cranes impacts differently on the VHT depending on the number of containers to move. On the other hand, the interactions CD and CG imply that depending on the number of quay cranes used in the loading and discharging process, the number of trucks and the rehandles will impact differently on the average VHT.

Table 3 ANOVA for average VHT

Source	*Df*	*Sum of squares*	*Mean square*	*p-value*	*Contri. (%)*	*Cum. contri. (%)*
A	1	225.596	225.596	0.000	64.41	64.41
C	1	80.075	80.075	0.000	22.86	87.27
D	1	16.994	16.994	0.000	4.85	92.12
AC	1	5.712	5.712	0.000	1.63	93.75
CD	1	3.511	3.511	0.000	1.00	94.76
F	1	3.511	3.511	0.054	1.00	95.76
E	1	1.767	1.767	0.164	0.50	96.26
G	1	1.353	1.353	0.221	0.39	96.65
B	1	0.442	0.442	0.479	0.13	96.77
Error	24	11.297	0.856		3.23	100.00
Total	31	350.258				

Note: R-squared = 0.9413 (adjusted R-squared = 0.9242).

An analysis of variance was used to evaluate the effects of the seven factors and their selected interaction at two-level on VHT. It is necessary to note that, when using ANOVA, three main assumptions must be checked: normality, homogeneity of variance, and independence of residuals. We did these checks and found no basis for questioning the validity of the experiments. The results (see Table 3) indicate that: the number of containers to move (A), the number of quay cranes used (C), and the number of trucks used per quay crane (D) are significant at the level $\alpha = 0.05$ (p-value = 0.000 in all cases). These variables explain the 92.12% of the observed VHT variability. The interactions among these factors are also significant; therefore, we cannot consider the effects of these factors separately. The adjusted $R^2 = 92.42\%$ indicates the adequacy of the model.

5.2 The impact of yard configuration and terminal resource allocation on VHT

This section analyses the behaviour of the VHT under a set of scenarios and operational strategies, with the aim of determining the impact of the yard configuration and terminal (yard side and seaside) resource allocations on this performance criterion. Four scenarios were constructed to resemble possible instances under which the vessels would operate on ATP. From the experimental analysis it was observed that the workload (total number of containers to move) and the previous planning decisions on both the yard side (i.e., the yard planning strategy) and seaside (the number of quay cranes and the number of internal trucks), are significant for the VHT. Therefore, these factors were included within the design of scenarios and operational strategies.

Every *scenario* (see Table 4) is constructed with a combination of the following factors:

1 the number of containers to transfer in the discharging process

2 the number of containers to transfer in the loading process

3 the yard configuration.

The yard configuration is a consequence of previous yard decisions, and it represents the yard organisation level (see Table 4). On the other hand, every *operational strategy* (see Table 5) is designed considering:

1 the number of quay cranes to assign to the vessel's operation

2 the number of trucks to assign per quay crane

3 the number of yard cranes to assign to the vessel's operation

4 the decision whether or not to avoid receiving containers from external trucks in the block where a vessel is being loaded to get a loading-optimised grounding strategy

5 the decision whether or not to assign the containers discharged from the vessel to the blocks with fewer deliveries to external trucks, to get a discharge-optimised grounding strategy.

Note that these parameters are user-defined inputs into the simulation model described in Section 4.

Table 4 Parameter setting for workload and yard planning level under different scenarios

	Scenario	*Loading/discharging balancing condition*	*Yard configuration*		
			% of reshuffling moves	*% double moves*	*No. of blocks for loading*
1	Unbalanced workload – disorganised	35/65 (unbalanced)	5	5	5
2	Unbalanced workload – organised	45/55 (balanced)	2	20	3
3	Balanced workload – disorganised	35/65 (unbalanced)	5	5	5
4	Balanced workload – organised	45/55 (balanced)	2	20	3

Table 5 Parameters used to model the operational strategies

Description	*Parameter setting*
Number of quay cranes	Within the range (2, 3)
Number of internal trucks per quay crane	Within the range (4, 10)
Number of yard cranes involved in the operation	Within the range (2, 6)
Application of best practice # 1: avoid receiving containers from external trucks in the block at which a vessel is being loaded.	Applied or not applied
Application of best practice # 2: to assign the containers unloaded from the vessel to the blocks with the fewest deliveries to external trucks.	Applied or not applied

Four scenarios were defined with regard to the workload balancing conditions and the yard configuration. Each scenario is further described below:

1. Scenario with unbalanced import/export ratio and a disorganised yard – it is assumed that the yard had been disorganised previous to the arrival of a vessel, with more discharging operations.
2. Scenario with unbalanced import/export ratio and an organised yard – it is assumed that the yard had been well organised previous to the arrival of a vessel, with more discharging operations.
3. Scenario with balanced import/export ratio and disorganised yard – it is assumed that the yard had been disorganised previous to the arrival of a vessel, with a similar number of discharging and loading operations.
4. Scenario with balanced import/export ratio and organised yard – it is assumed that the yard had been well organised previous to the arrival of a vessel, with a similar number of discharging and loading operations.

At least 1,200 simulation runs were required for each scenario. Four operational strategies were defined with the assistance of the operations manager and personnel of ATP, to resemble the actions of the terminal when facing each scenario. The average VHT associated with each feasible operational strategy was recorded. Results are summarised below.

5.2.1 Results for scenario 1 with an unbalanced import-export ratio and a disorganised yard

Table 6 shows the operational characteristics of each strategy for scenario 1, which can be interpreted as follows:

Strategy A Uses two quay cranes, six internal trucks per quay crane, and three yard cranes for servicing the vessel: 2 for loading (2L) and 1 for discharging (1D). In this strategy, the terminal operator avoids receiving containers from external trucks in the blocks where a vessel is being loaded.

Strategy B Uses two quay cranes, eight internal trucks per quay crane, and six yard cranes for servicing the vessel. In this strategy, the terminal operator is allowed to receive containers from external trucks in the blocks from which a vessel is being loaded, but seeks to send the discharged containers from the vessel to the blocks that have fewer deliveries to external trucks.

Strategy C Uses three quay cranes, six internal trucks per quay crane, and three yard cranes for vessel service. In this strategy, the terminal operator avoids receiving containers from external trucks in the blocks from which a vessel is being loaded.

Strategy D Uses three quay cranes, eight internal trucks per quay crane, and six yard cranes for vessel service. In this strategy, the terminal operator is allowed to receive containers from external trucks in the blocks from which a vessel is being loaded, but seeks to send the discharged containers from the vessel to the blocks that have fewer deliveries to external trucks.

Table 6 Operational characteristics of feasible strategies for scenario 1

Description	*Operational strategy*			
	A	*B*	*C*	*D*
Number of quay cranes	2	2	3	3
Number of internal trucks per quay crane	6	8	6	8
Number of RTGs involved in the operation	2L1D	2L4D	1L2D	4L2D
Avoid receiving containers from external trucks in the block in which a vessel is being loaded.	Y	N	Y	N
Assign the unloaded containers from the vessel to the blocks with the fewest deliveries to external trucks.	N	Y	N	Y

Figure 6 The impact of different yard planning strategies and workload on VHT, for scenario 1 (see online version for colours)

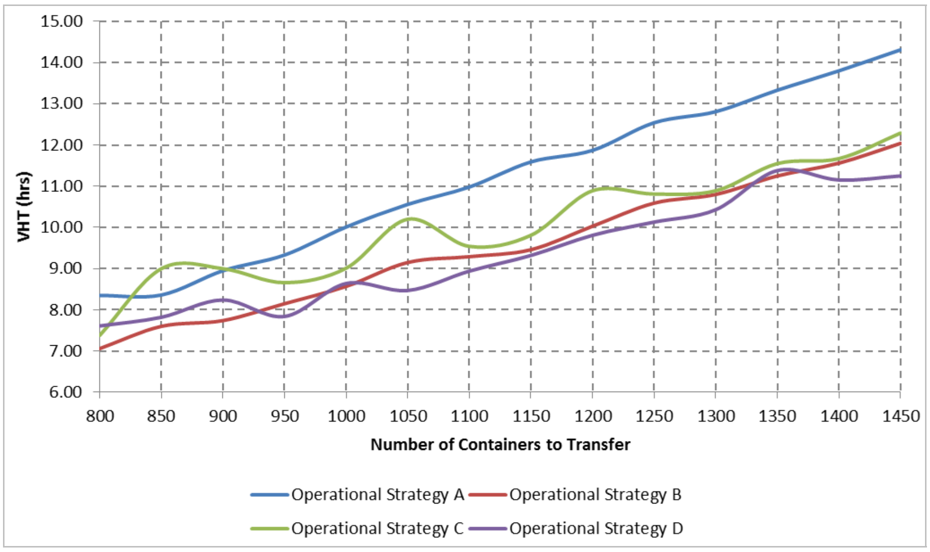


Figure 6 shows how the average VHT increases as the number of containers to transfer increases. The figure shows that the average VHT could be reduced if the discharge-optimised grounding strategy is implemented with eight trucks per quay crane if the yard presents a low planning status. A deeper analysis reveals that even though operational strategy B uses one less quay crane, and consequently fewer internal trucks than in operational strategy D, their performances are similar, because the former, (operational strategy B), defines a more efficient deployment decision of the yard cranes, i.e., it uses more yard cranes for discharging operations given that 65% of the containers are discharged. Operational strategy A seems to be inefficient compared with the other strategies.

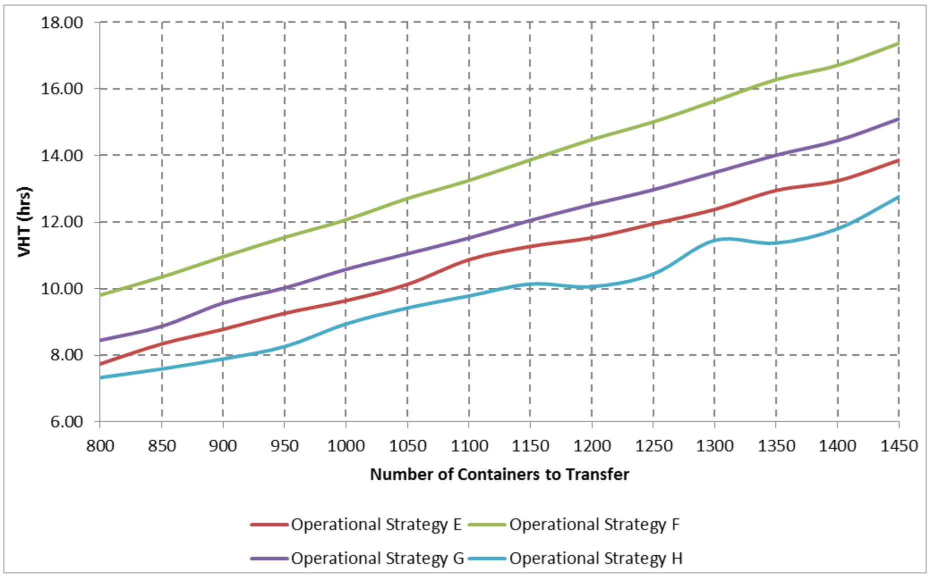
5.2.2 *Results for scenario 2 with an unbalanced import-export ratio and an organised yard*

Table 7 shows the operational characteristics for each strategy in scenario 2. The interpretation of these strategies is analogous to those of scenario 1. Figure 7 shows the impact of each operational strategy on VHT. Note that in an organised yard, the impact of each operational strategy is more evident. The figure shows that the average VHT could be significantly reduced if operational strategy H is implemented. As expected, the operational strategy with a better allocation of yard cranes, in relation to the loading/discharging containers, is the best strategy. The strategies that seek to send the discharged containers from the vessel to the blocks with fewer deliveries to external trucks result in lower VHTs.

Table 7 Operational characteristics of feasible strategies for scenario 2

Description	*Operational strategy*			
	E	*F*	*G*	*H*
Number of quay cranes	3	2	3	2
Number of internal trucks per quay crane	8	8	6	8
Number of RTG involved in the operation	1L2D	3L3D	2L4D	2L4D
Avoid receiving containers from external trucks in the block from where a vessel is being loaded.	N	N	Y	Y
To assign the unloaded containers from the vessel to the blocks with fewer deliveries to external trucks.	Y	Y	N	Y

Figure 7 The impact of different yard planning strategies and workload on VHT, for scenario 2 (see online version for colours)



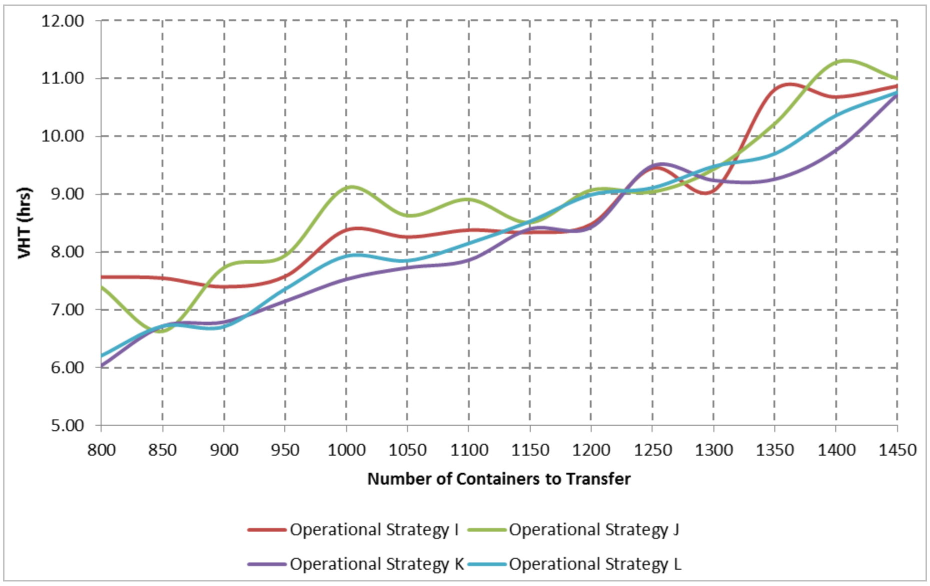
5.2.3 Results for scenario 3 with balanced import-export ratio and disorganised yard

Table 8 shows the operational characteristics for each strategy in scenario 3, and Figure 8 shows how the average VHT changes. The interpretation of these strategies is analogous to those of scenario 1. In this scenario, it is difficult to identify the best operational strategy to use, because the allocation of yard cranes, and the implementation of best practices oriented to mitigating the congestion at the yard are not consistent.

Table 8 Operational characteristics of feasible strategies for scenario 3

Description	*Operational strategy*			
	I	*J*	*K*	*L*
Number of quay cranes	3	3	2	2
Number of internal trucks per quay crane	6	6	8	8
Number of RTG involved in the operation	3L3D	2L4D	1L2D	4L2D
Avoid receiving containers from external trucks in the block from where a vessel is being loaded.	Y	N	N	Y
To assign the unloaded containers from the vessel to the blocks with fewer deliveries to external trucks.	Y	N	N	N

Figure 8 The impact of different yard planning strategies and workload on VHT, for scenario 3 (see online version for colours)



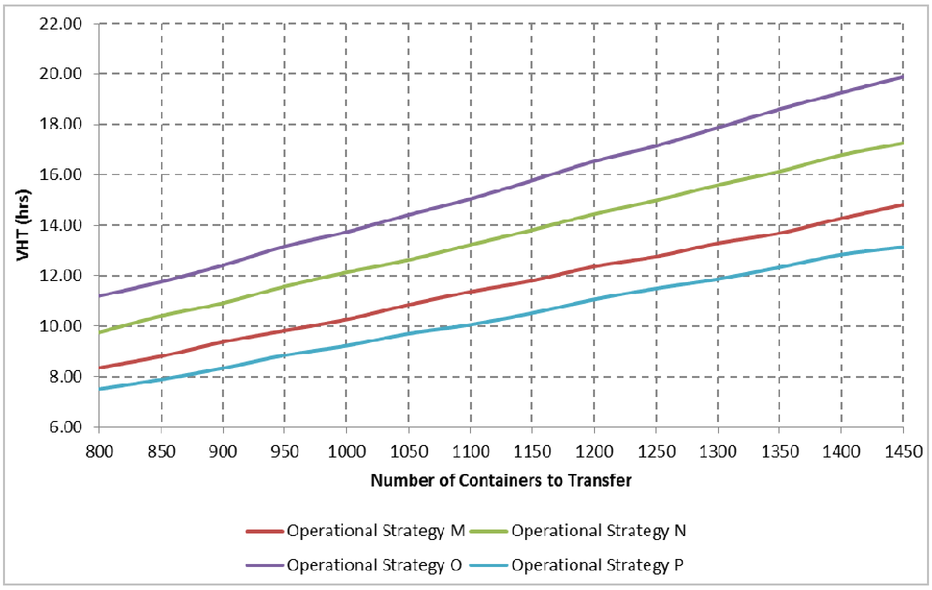
5.2.4 Results for scenario 4 with a balanced import-export ratio and an organised yard

Table 9 shows the operational characteristics of each strategy for scenario 4. The interpretation of these strategies is analogous to those of scenario 1. Figure 9 shows how the average VHT increases as the number of containers to move increases. The figure shows that the average VHT could be reduced significantly if operational strategy P is implemented. In this scenario, the best operational strategy uses three quay cranes and six yard cranes, while neither of the two best practices are employed. Note that operational strategy M shows similar results with a lower number of yard cranes and trucks per quay cranes, because both best practices are employed.

Table 9 Operational characteristics of feasible strategies for scenario 4

Description	*Operational strategy*			
	M	*N*	*O*	*P*
Number of quay cranes	3	2	2	3
Number of internal trucks per quay crane	6	8	6	8
Number of RTG involved in the operation	2L1D	2L1D	3L3D	3L3D
Avoid receiving containers from external trucks in the block from where a vessel is being loaded.	Y	Y	Y	N
To assign the unloaded containers from the vessel to the blocks with fewer deliveries to external trucks.	Y	Y	Y	N

Figure 9 The impact of different yard planning strategies and workload on VHT, for scenario 4 (see online version for colours)



From the previous experiments, it is concluded that:

- The number of containers to move in the loading and discharging operation, i.e., the workload, is the main factor that affects the VHT statistically, with a positive effect. This means that the VHT increases as the workload increases.
- The number of terminal resources used in the loading and discharging operation (i.e., quay cranes, trucks, and yard cranes) is also significant for VHT, with a negative effect. This means that the VHT decreases as the number of quay cranes, trucks, and

yard cranes used in the loading and discharging operation increases. These results are consistence with the literature, where Ng and Mak (2005) and Iris et al. (2018) argue that vessel turnaround times are highly dependent on the effectiveness of allocation and scheduling decision of key resources, such as berths, yards, quay cranes, yard cranes and trucks.

- The interaction between the workload and the number of quay cranes shows that the reduction of the VHT, caused by an increment in the number of quay cranes, is more obvious when there are more containers to move. This is consistent with Taleb-Ibrahimi et al. (1993) that quantify the performance of a container terminal according to the amount of space and number of handling transfers they require.
- The interaction between the number of quay cranes and the number of trucks shows that for a given number of containers to move, the reduction of the VHT caused by an increment in the number of trucks is more evident when fewer quay cranes are used in the loading and discharging operation. This result is consistent with the findings of Cao et al. (2010) who found significant correlation between the equipment in quayside handling area and the terminal stacking area.
- Under the scenario in which the yard presents a low planning status, i.e., it is disorganised prior to the arrival of the vessel mainly because export containers are not efficiently stacked in the yard, the average VHT reaches its best value when a discharge-optimised grounding strategy is implemented, combined with the use of 8 trucks per quay crane. In this case, it is not recommended to receive containers from external trucks in the block from which a vessel is being loaded, however, the unloaded containers from the vessel should be assigned to the blocks that have fewer deliveries to external trucks. It should be noted that if this situation prevails, an efficient yard crane deployment decision may reduce the number of quay cranes required and favours the efficient control of loading and discharging operations. In Roy and Koster (2018) it is argued that the throughput performance of the ship loading and unloading operations may be affected by the topology of the travel path of the trucks, the number of trucks, and the configuration of the yard layout; which is consistent with this finding. It means that, if the yard is not well-organised, an efficient deployment of yard cranes reduces the number of quay cranes required in the operation, at the expense of using more trucks per quay crane.
- In the scenario in which the yard is well organised, i.e., containers are stacked in positions that are more adequate to the loading sequence, the average VHT reaches its best values when better yard crane allocation decisions were made, in relation to loading/discharging containers. Note that the proper deployment of yard cranes and the application of best practices are significant for reducing the average VHT in organised yards.
- In the scenario in which the yard is disorganised with a balanced ratio of import and export containers, the VHT decreases as the number of trucks increases. Here the application of best practices isn't a determining factor in the performance.
- In the scenario in which the yard is organised with a balanced number of loading and unloading moves, the experiments show that the best operational strategy uses three quay cranes, eight trucks, and six yard cranes, without implementing either of the two best practices. However, similar results are attained with an operational strategy

that employs a lower number of terminal resources (the same number of quay cranes, but only 6 trucks per quay crane, and three yard cranes), but it does implement the two best practices. The conclusion is that the implementation of the best practices is the determining factor for a better performance.

6 Managerial insights

This section describes the managerial insights, derived from the study, which can be used by practitioners to support their daily planning decisions, in relation to container loading and discharging operations. From a general point of view, well-organised resource planning decisions in conjunction with the application of grounding strategies that optimise the horizontal transport of containers have a positive impact on savings, as a result of an efficient use of resources (i.e., quay cranes, yard cranes, and trucks) and an increase in the levels of service to customers (shipping lines).

More specifically, below there are managerial insights that take the form of recommendations, of specific actions for both organised and disorganised yards:

- If the yard is not well-organised, an efficient deployment of yard cranes reduces the number of quay cranes required in the operation, at the expense of using more trucks per quay crane. This strategy will reduce the VHT, providing better control of loading and discharging operations. In this case, the application of the grounding strategies that optimise the horizontal transport of containers (i.e., avoiding receiving export containers from external trucks simultaneously while a vessel is being served; and stacking import containers in blocks that have a lower number of scheduled containers to be dispatched to external trucks) is recommended. By avoiding stacking unloaded containers into blocks where, at the same time, containers are scheduled to be dispatched, the cargo transferring between the yard and the vessel improves, by avoiding the congestion in the yard created by the combination of internal and external trucks. In case all the blocks have containers scheduled to be dispatched, it would be desirable to stack containers in those blocks with fewer containers to be dispatched. However, it could occur that there would be no available blocks with few import containers scheduled to be dispatched. In this situation, a challenge that the port terminal manager may face is related to a critical feature: the lack of available space in the yard caused by the disorganised yard's low planning status. Therefore, we recommend scheduling a marshalling of containers at the yard, selecting one day with a lighter workload on which to better organise the location of the future containers arriving at the yard. The container terminal may also need to consider additional investments, or a layout re-design, to increase its current stacking capacity.
- If the yard is well-organised, the application of the grounding strategies that optimise the horizontal transport of containers is the determining factor for better performance, when combined with good yard crane allocation decisions, in relation to the loading/discharging containers. This is consistent with the results obtained by Roy and Koster (2018), who analyse two scenarios (cases) varying the proportions of container loading and unloading. Case 1: loading 33%, unloading 67%, case 2: loading 67%, unloading 33%. They found that that most of the best performing stack layout configurations are identical across the cases, concluding that good

configurations are robust to varying proportion of loading and unloading transactions. It is also consistent with Zhen (2016) who shows that a big yard (with the size of 160 sub-blocks) can save the total truck travelling time by 8% when its yard template is optimised (considering the yard truck traffic flows), and the widely used protocol of high-low workload for mitigating congestion is employed. In this case, similar challenges are faced. If the yard has high utilisation (more than 70%), there may be congestion, and it may not be possible to have blocks that have only a few containers to be dispatched. If the dispatching is postponed, then less space is available, and the managers can face an unworkable situation. However, if the yard is better organised, the loading and unloading process will be faster as few rehandles may be incurred. One possible solution is to relocate the containers to be dispatched in fewer blocks in order to separate the operations of servicing a vessel from dispatching inbound containers to external trucks. This requires additional rehandles of containers, but on the other hand, minimises congestion and allows providing better service to both the land and maritime carriers. It also contributes to reducing the dwell times of the containers which allows better utilisation of space at the yard.

- In general terms, we observe that when the import/export ratio is more balanced, a more balanced deployment of equipment is also suggested and that in general, the equipment's deployment is a determining factor in VHT. Challenges that may face the port terminal manager are the lack of availability of equipment, or disruptive events in which certain equipment may fail to operate. In this case, we recommend that the deployment of equipment should be done under similar conditions to the best strategy found in the simulations. Likewise, we recommend to postpone the dispatching of containers to external trucks, since this also avoids congestion and allows faster servicing of the vessel.

7 Conclusions and future research

The container loading and discharging process is complex in its nature. In addition, port terminal managers are currently facing an increased number of constraints that limit their capacity to react to disruptive events. This paper reports various operational strategies that were tested to analyse their impacts on container loading and discharging operations. The operational strategies were evaluated, with regard to VHT, under four scenarios that were constructed to resemble possible situations in which a vessel would be serviced at the container terminal. As a basis for our study, an experimental framework was proposed, based on a simulation model, comparison of scenarios, and search experimentation, to obtain robust conclusions about the operational strategies that can be implemented to improve the loading and discharging process.

Computational results of our simulation study provide evidence of the benefits that can be obtained by the implementation of the various operational strategies that were evaluated. Our empirical findings are related to:

1 identify the impact of various factors (e.g., allocation of resources) on the VHT

2 identify the impact of yard configuration on the VHT

3 identify the most appropriated strategies to reduce VHT on organised and not well-organised yards.

Results indicate that the proper use of quay cranes and employing the discharging optimised grounding strategy is essential to achieve significant benefits with respect to minimising VHT. However, the importance of each criterion is expected to vary from terminal to terminal. This supports the idea that a proper yard planning strategy is necessary to reduce the number of movements. This contributes to strengthening the competitiveness of ports, since the reduction of VHT could contribute to increasing the transport of cargo to their ports.

As future research, we propose combining simulations with optimisation models to determine the optimal allocation of terminal resources for each scenario realised. In addition, we propose evaluating the integration of other operational policies, such as berth allocation (in this case we assume that the decision has already been made), and the assignment of appointments to external trucks for stacking and dispatching operations based on the actual workload at the yard.

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